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Collision Avoidance channel access scheme for a V2I communication system by using Adaptive beam forming method

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Abstract

Smart antenna technology is used in V2I communication system to increase service coverage area. Infrastructure forms multiple directional beams using adaptive beam forming to detect the newly arrived vehicles within its coverage area. To communicate vehicle with infrastructure (V2I communication) first it should access the channel. During contention based channel access, collisions occur when more than one vehicle selects the same minislot to transmit an access signal to infrastructure. To reduce these collisions Random channel accessing scheme, Discovery beam channel access scheme and Group based channel accessing schemes are performed. Through analysis and simulation results group based channel access scheme shows better performance than other two schemes.

"1.Introduction"

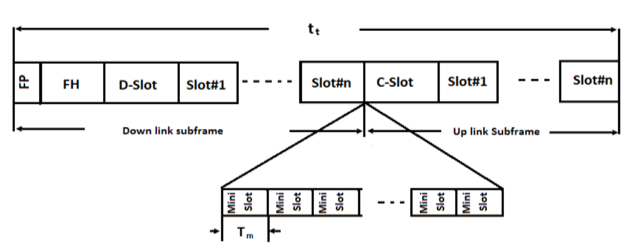
As the number of vehicles on the road increases, delay increases to collect the toll manually. Electronic Toll Collection (ETC) system is used to avoid delay that involves non-stop tax collection. To achieve this first vehicle should communicate infrastructure by wirelessly. In vehicle communications, service requirements can be covered using two types of network topologies: communications between vehicle and infrastructure, and communications among vehicles. In the first case, on-board services require a connection with the infrastructure located at the vehicle side. This kind of connectivity is usually named as Vehicle to Infrastructure (V2I) communication. An example of such technology can be found in electronic tax collection systems, where drivers are charged automatically, according to some vehicle and vehicle parameters [1].

In V2I systems, the main technologies involved are Dedicated Short Range Communications (DSRC), infrared, and wireless LAN [2]. On the other hand, the second group of services with connectivity requirements is the vehicle to vehicle (V2V) communication. In a conventional V2I communication system that uses an Omni directional antenna, vehicles cannot be found efficiently by an infra that has the gain of the Omni antenna. To solve this problem, smart antenna is used instead of Omni directional antenna.

Smart antenna is array of antenna with digital signal processing unit that can produce radiation pattern in desired direction and nulls in undesired direction. There are two types of beam forming methods. Switched beam forming and Adaptive beam forming. Switched beam forming consists fixed, predetermined beams. If target change its direction, then beam will be shifted to target direction. Adaptive beam forming produces beam in target direction and nulls in interference direction [3].

Remaining paper is organized as follows; frame structure for V2I communication is in section II channel access procedure of V2I communication in Section III. Section IV describes the channel accessing schemes. The simulation results are presented in Section V. Conclusion in Section VI.

"2.Frame structure"

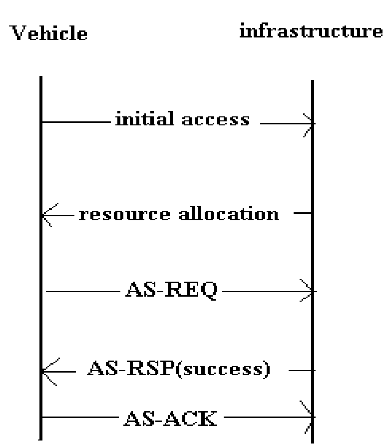


"Figure 1.Frame structure of V2I communication system."

V2I communication system with a time division multiple-access (TDMA)-based frame structure as shown in Fig. 1. Each frame has a fixed duration T_f and consists of downlink and uplink subframes. Downlink means data from infra to vehicle and uplink means data from vehicle to infra. Each subframe consists of time slots that have a fixed duration Ts. The first downlink slot is allocated for the transmission of the frame preamble (FP) and frame header (FH). The FP indicates the start of each frame. The FH includes the ID and system information of an infra as well as control information about slot usage and allocation. By receiving the FH, each vehicle obtains the schedule of upcoming data transmission and reception, and their destinations. The first uplink slot can be used as a contention slot (C-slot), which consists of mini-slots that have a fixed duration of Tm. A vehicle that would like to do initial access to infra selects a mini-slot and transmits an access signal at the corresponding mini-slot.

The second downlink slot can be used as a discovery slot (D-slot). During the period of D-slot, an infra detect vehicles that have newly arrived within its coverage area by forming multiple discovery beams. A discovery beam includes a discovery preamble (DP), the discovery beam's ID, the location of the infra, and information about the C-slot. The DP indicates the presence of the infra to arriving vehicles. The C-slot information describes the usage of mini-slots that are allocated to each discovery beam. In the V2I communication system, a sequence of k frames is repeated with a period of $T_{p.}$ The first frame contains a D-slot to detect newly arrived vehicles. The second frame contains a C-slot to provide the vehicles with the opportunity to access channels. The other frames in the sequence contain only data slots that can be used for exchanging data between the infra and vehicles. Thus, the infra forms discovery beams with a period of Tp[4].

"3.Channel access procedure"



"Figure.2. channel access procedure."

In the V2I communication system, a channel access procedure consists of two phases: initial access and association. After receiving the discovery beam, a newly arrived vehicle enters the initial access phase. In this phase, the vehicle selects one of the mini-slots in the C-slot. Then, by forming a directional beam toward the infra, the vehicle transmits an access signal at the selected mini-slot in order to set up the association between the infra and the vehicle. When the infra detects that a signal has been transmitted using a particular mini-slot, it allocates uplink resource for the association to the corresponding vehicle in the mini-slot. In the association phase, the vehicle transmits an association request (AS-REQ) message by using the allocated resource and activates T_{assoc} timer. When the infra correctly receives the AS-REQ message, it transmits an association response (AS-RSP) message indicating the success of the association to the vehicle. For responding to the AS-RSP message, the vehicle transmits an association acknowledge (AS-ACK) message[5]. Then, the association between the infra and the vehicle is set up and the association phase is completed In the initial access phase, a collision occurs when two or more vehicles select the same mini-slot and therefore transmit their signal at the same time. If a collision occurs, the vehicles that are involved in the collision and the infra cannot detect the collision immediately, because the received signal for each mini-slot is detected by the infra based on on/off detection. As a consequence, in the association phase, the AS-REQ messages that are transmitted by the vehicles that are involved in the collision will also collide. Therefore, the collisions that occur during the initial access increase the channel access delay of vehicles. When the infra fails to decode the AS-REQ message due to the collision, it broadcasts the AS-RSP message indicating the failure of the association. After receiving the failure message, the vehicles that are involved in the collision go back to the initial access phase and repeat the channel access procedure. In addition, if the vehicle that transmitted the AS-REQ message does not receive any AS-RSP message from the infra until the T_{assoc} timer is expired, it goes back to the initial access phase and repeats the channel access procedure. After succeeding in the channel access, the vehicle can exchange information with the infra until it moves outside the service coverage [5] [6].

"4.Channel accessing scheme"

In a V2I communication system, an infra can be located at the road side. Consider a V2I communication system in which an infra covers L lanes of roads that come from J different directions where l =

1, 2, . . . , L is the index of the lane. The infra forms a discovery beam j to detect vehicles in adjacent lanes that have arrived from the same direction j. Therefore, j = 1, 2, . . . , J can be used for both the index of discovery beam j and the corresponding direction j. The total number of mini-slots in a C-slot is C where c = 1, 2, ...,C is the index of the mini-slot. Herein, we assume that the arrival process of vehicles on a lane l is assumed as a Poisson process with an arrival rate λ_l^t [vehicles/s]. The validity of this assumption has been verified by empirical data in real environments [6]. Under this assumption, the distribution of the lane-level inter-arrival time between vehicles follows an exponential distribution with parameter λ_l^t for lane l.

By summing the inter-arrival rate of all lanes that come from direction j, the direction-level arrival rate of vehicles for lane j can be expressed as

$$\lambda_j = \sum_{l \in L_j} \lambda_l^t \quad (1)$$

Where j=1,2,……..J

where $L_j = \{l$ / lane l from direction $j\}$ is the index set of lanes from the same direction j. Thus, the average number of vehicles that arrive from direction j during a time period t can be expressed as

$$V_j(t) = \lambda_j t \text{ where } j=1,2,\ldots J \quad (2)$$

As a consequence, the average number of vehicles that arrive from all directions during a time period t can be expressed as

$$V(t) = \sum_{j=1}^{J} V_j(t) \quad (3)$$

4.1. Random channel access scheme

Discovery beams are formed with a period of T_p. V (T_p) represents the total number of vehicles that arrive from all directions during T_p. In this scheme,V (T_p) vehicles receive the discovery beams and perform channel access at the same time, each of V (T_p) vehicles selects one of C mini-slots in the C-slot with equal probability of 1/C. The problem that V vehicles select C mini-slots is similar to the occupancy problem of N balls in M cells [7]. Let C_r denote the number of mini-slots, each of which contains exactly r vehicles that select a mini-slot. C_0 is the number of empty mini-slots, each of which is not selected by any vehicles. C_1 is the number of successful mini-slots, each of which is selected by only a vehicle. Using the occupancy problem, given that the number of vehicles V=v and the total number of mini-slots $C = c$, the probability that $C_0 = c_0$ and $C_1 = c_1$ is calculated as

$$P(c_0, c_1, v, c\}$$
$$= \Pr\{C_0=c_0, C_1 = c_1, V = v, C = c\}$$

$$= \sum_{i=0}^{c-c_0-c_1} (-1)^i \sum_{j=0}^{i} \binom{c_0+i-j}{c_0}\binom{c_1+j}{c_1} S_{C_0+i-j, c_1+j} \quad (4)$$

where the combination probability of $C_0 = c_0$ and $C_1 = c_1$

$$= S_{c_0,c_1} = \binom{c}{c_0}\binom{c-c_0}{c_1}\frac{\binom{v}{c_1} c_1!(c-c_0-c_1)^{v-c_1}}{c^v} \quad (5)$$

The average number of vehicles that succeed in the channel access during T_p are calculated the average number of successful mini-slots as follows. Since V (T_p) vehicles select one of C mini-slots randomly, using Eq. (4), $P(c_0, c_1, V(T_p), C)$ can be calculated. By summing $P(c_0, c_1, V(T_p), C)$ over $0 \leq c_0 \leq C$, the probability that $C_1 = c_1$ can be calculated as

$$\Pr\{C_1 = c_1\} = \sum_{i=0}^{C} P(i, c_1, V(T_P), C) \quad (6)$$

where $c1 = 0, 1, \ldots, C$. The average number of successful mini-slots in the C-slot as follows

$$E[C_1] = \sum_{i=0}^{C} i \Pr\{C_1 = i\} \quad (7)$$

Thus, the utilization ratio of the C-slot can be expressed as

$$U = E[C_1]/C \quad (8)$$

which is the proportion of the number of successful mini-slots over the total number of mini-slots in the C-slot. In this scheme, all vehicles that have arrived select a mini-slot at random among the total number C of mini-slots, collisions between vehicles that arrived from the same direction and those that arrived from different directions can occur during channel access.

4.2. Discovery beam based channel access scheme

In this scheme, an infra allocates different mini-slots to each discovery beam, in order to avoid collisions between vehicles that have come from different directions.

The total number C of mini-slots, the number of minislots that are allocated to a discovery beam j is determined by

$$C^j = \left\| \frac{\bar{\lambda}_j}{\sum_{i=1}^{J} \bar{\lambda}_i} C \right\| \qquad (9)$$

Where j=1, 2……..J

Which is proportional to the average rate $\bar{\lambda}_j$ at which vehicles arrive from direction j where the function $|x|$ rounds x to the nearest integer.

Given that discovery beam j is formed with a period of T_p, the total number of vehicles that arrive from direction j during T_p is $V_j(T_p)$. As a consequence, $V_j(T_p)$ vehicles receive the discovery beam j and perform channel access at the same time. By receiving discovery beam j, $V_j(T_p)$ vehicles can obtain the information about the mini-slots that are allocated to the discovery beam j. In this scheme, given that the number of mini-slots allocated to discovery beam j is C_j, each of $V_j(T_p)$ vehicles selects one of C_j mini-slots with equal probability of $1/C_j$.

By using the similar way used in the random scheme, calculate the average number of successful mini-slots in a discovery beam j as follows. Using Eq. (4), the probability of $C_1 = c_1$ for a direction j can be calculated as

$$\Pr\{C_1^j = c_1\} = \sum_{i=0}^{C^j} P(i, c_1, V_j(T_p), C^j) \qquad (10)$$

where $c_1 = 1, 2, \ldots, C_j$. Thus, we can obtain the average number of successful mini-slots in a discovery beam j as follows

$$E[C_1^j] = \sum_{i=0}^{C^j} i \Pr\{C_1^j = i\} \qquad (11)$$

Therefore, the utilization ratio of the C-slot can be expressed as

$$U = \sum_{j=1}^{J} E[C_1^j] / C \qquad (12)$$

which is the proportion of the sum of the number of successful mini-slots in each discovery beam over the total number of mini-slots in the C-slot.

In this scheme, since the separated mini-slots are allocated to each discovery beam, vehicles that arrived from different directions select different mini-slots. As a consequence, collisions between vehicles that arrived from different directions can be avoided. However, since vehicles that arrived from the same direction select a mini-slot at random among the same mini-slots, collisions between the vehicles can still occur during channel access.

4.3. Group-based channel access scheme

To solve collision problems that occur in previous schemes, group-based channel access scheme is performed. Basically, in this scheme, an infra allocates different mini-slots to each discovery beam by using the same method in the discovery beam based scheme. In addition, the group of vehicles that intend to access a channel at the same time should be coordinated, to avoid collisions between vehicles that have arrived from the same direction. The group of vehicles consists of adjacent vehicles that have arrived from the same direction. By receiving the discovery beam j, the vehicles in one group can simultaneously obtain the information about the mini-slots that are allocated to discovery beam j. Then, vehicles in the same group intend to access a channel to the infra at the same time. Upon receiving the discovery beam, each vehicle broadcasts its position and velocity which are obtained using GPS to all other vehicles in the group. By using space division multiple access (SDMA)-based V2V communication [8]-[9], each vehicle can communicate with other vehicles in the same group that travel on the same lane or different lanes without any collisions.

By receiving this information from all other vehicles in the group, each vehicle can know its own position in the order of initial access, which is mapped to the index of the mini-slot. Vehicles that desire access to the infra are ranked in order of proximity to the infra, with closer proximity yielding priority, so the closest vehicle gets the first mini-slot.

To analyze the number of successful mini-slots, consider two kinds of case. (1) The number of vehicles in one group is less than the number of mini-slots allocated to a discovery beam j, C_j. In this case, all the vehicles can access minislots according to their proximity ranking. (2) The number of vehicles in one group is greater than C_j. In this case, only vehicles whose proximity ranking ranges from 1 to C_j perform initial access at the same time. The rest of the vehicles

in the group wait until the next period of the discovery beam before attempting channel access. The number of vehicles that have arrived from direction j during T_p is $V_j(T_p)$, the average number of successful mini-slots in a discovery beam
j can be calculated as

$$E[C_1^j] = \begin{cases} V_j(T_p) & \text{if } C^j > V_j(T_p), \text{ for Case1} \\ C^j & \text{if } C^j \leq V_j(T_p), \text{ for Case2} \end{cases} \quad (13)$$

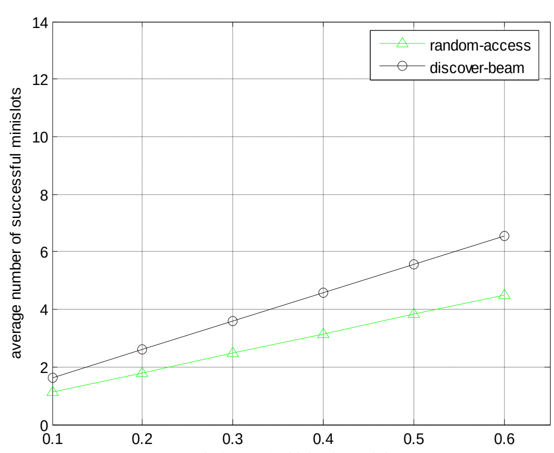
The separated mini-slots are allocated to each discovery beam. In addition, vehicles that arrived from the same direction determine their access order based on the distance between vehicle and infra. As a consequence, collisions between vehicles that arrived from the same direction and those that arrived from different directions can be avoided during channel access. Therefore, group based channel access scheme can achieve almost collision-free channel access.

Simulation parameters

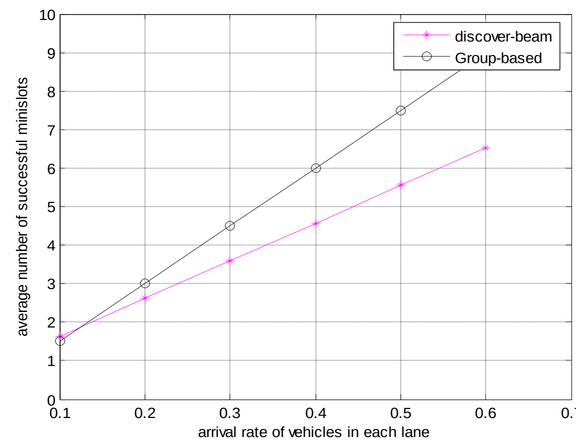
Beam width of discovery beam (BW)	30^0
Total number of mini-slots in the C slot (C)	20
Period of discover beams (Tp)	5 s

"Table.1.Simulation parameters."

"5. Simulation results"

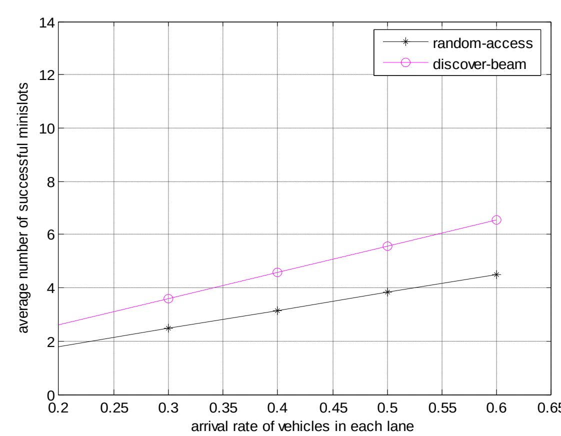


"Figure.3. Average number of successful minislots in a C-slot vs. arrival rate for symmetric traffic for $\lambda_1=\lambda_2$. For random access and discovery beam."



"Figure.4. Average number of successful minislots in a C-slot vs. arrival rate for symmetric traffic for $\lambda_1=\lambda_2$. For discovery beam and groupbased scheme."

Fig.3 and Fig.4. shows the average number of successful minislots in the C-slot for symmetric traffic. In the case of symmetric traffic, vehicles arrive from each of four lanes with the same arrival rate.



"Figure.5. Average number of successful minislots in a C-slot vs. arrival rate for asymmetric traffic for each lane for random access and discovery beam."

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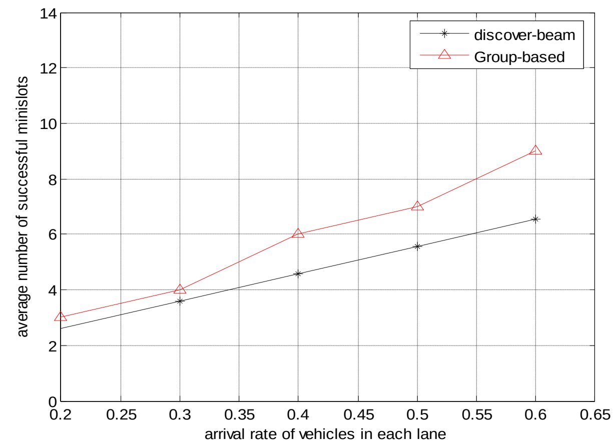
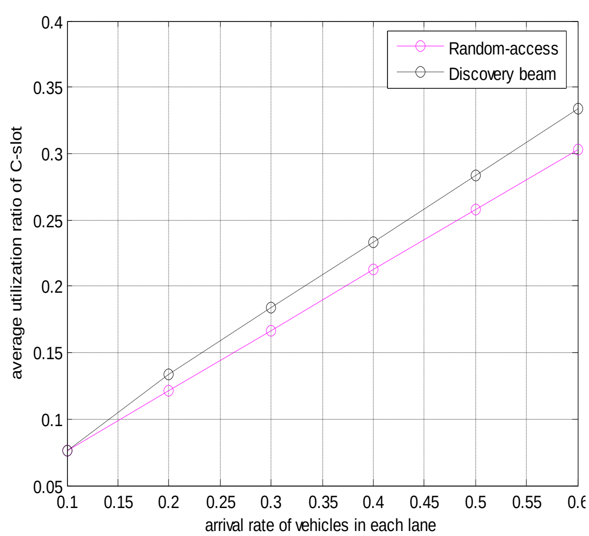


“Figure.6. Average number of successful minislots in a C-slot vs. arrival rate for asymmetric traffic for each lane for discovery beam and groupbased scheme.”

Fig.5 and Fig.6. shows the average number of successful minislots in the C-slot for asymmetric traffic. In the case of asymmetric traffic, the arrival rate of vehicles in lanes 3 and 4 is fixed at λ= 0.3, whereas the arrival rate of vehicles in lanes 1 and 2 varies from λ = 0.1 to 0.6.



“Figure. 7. Average utilization ratio of a C-slot vs. arrival rate for symmetric traffic for random access and discovery beam.”

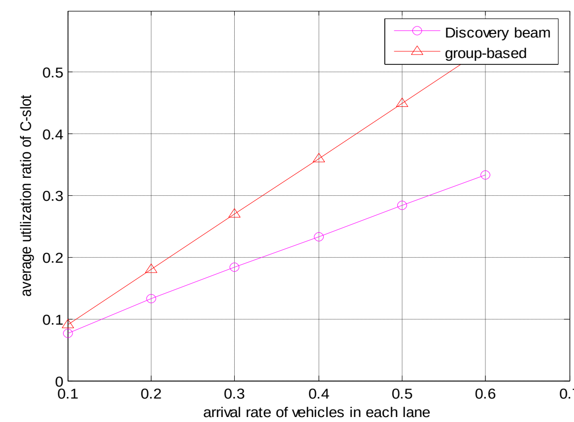
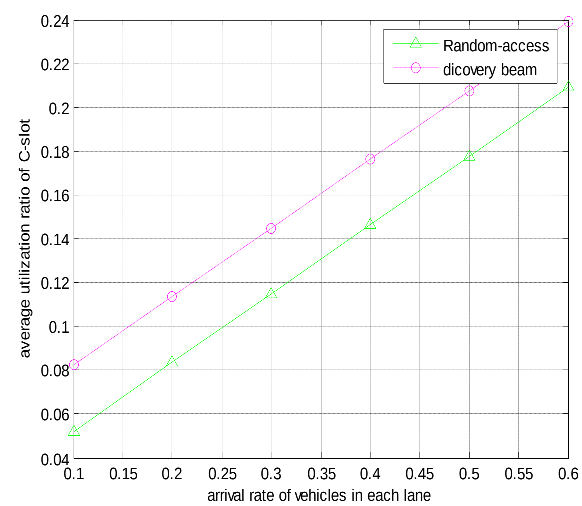
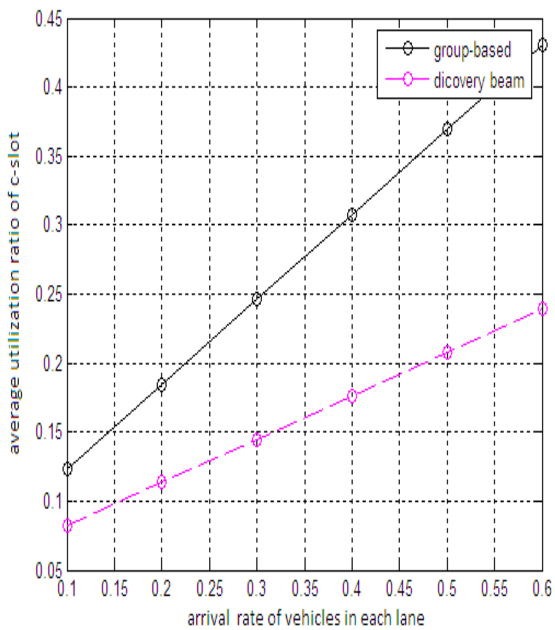


Fig. 8. Average utilization ratio of a C-slot vs. arrival rate for symmetric traffic for discovery beam and group based channel access scheme.

Fig.7 and Fig.8. shows Average utilization ratio of a C-slot for symmetric traffic. In the case of symmetric traffic, vehicles arrive from each of four lanes with the same arrival rate.



“Figure. 9. Average utilization ratio of a C-slot vs. arrival rate for asymmetric traffic for random access and discovery beam scheme.”



"Figure. 10. Average utilization ratio of a C-slot vs. arrival rate for asymmetric traffic for discovery beam and group based channel access scheme."

Fig.9 and Fig.10. shows the average utilization ratio of C-slot for asymmetric traffic. In the case of asymmetric traffic, the arrival rate of vehicles in lanes 3 and 4 is fixed at λ= 0.3, whereas the arrival rate of vehicles in lanes 1 and 2 varies from λ = 0.1 to 0.6.

The results show that the performance of the group-based access scheme is substantially better than that of the random access scheme and discovery beam scheme, because it achieves collision-free channel access. The group- based channel access scheme shows the best performance, regardless of whether the traffic is symmetric or asymmetric.

"6.Conclusion"

Smart antenna technology in V2I communication system increases the service coverage area. Group based channel access scheme can help to reduce the number of collisions that occur during channel access, whether the traffic is symmetric or asymmetric. Group based channel access scheme gives almost collision free channel access by reducing the collisions between vehicles from same direction and from different directions that occur during channel access. Therefore, the channel access delay of V2I communication system can be shortened and hence the system throughput can be further increased.

"7.References"

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